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(54) Abstract Title
Determining the noise variance of a received signal

(57) The effective noise variance of an input signal to a rake receiver is determined by receiving a first set of symbols having respective signal power levels and associated noise components, the noise components having a first noise variance level; calculating a second set of symbols each of which has a signal power level corresponding to the average of the signal power levels of a respective pair of symbols from the first set of symbols and associated noise components, the noise components having a second noise variance level; and calculating the effective noise variance of the input signal using the average symbol power level of the first symbol set and the average symbol power level of the second symbol set. The outputs from the fingers of the rake receiver are maximal ratio combined on the basis of the calculated noise variance.

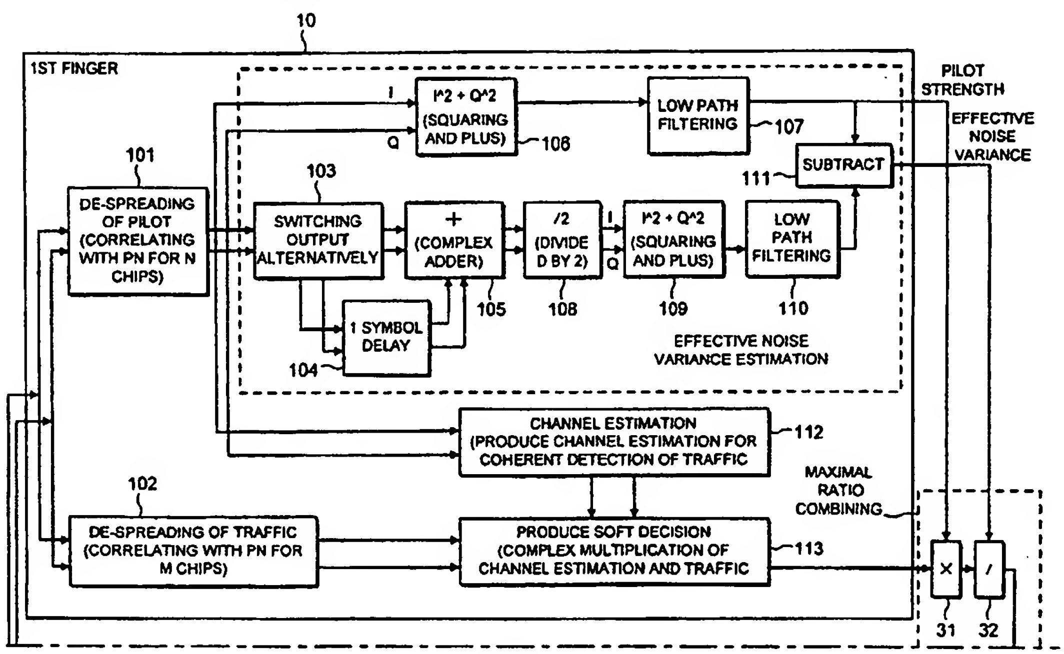

FIG. 1

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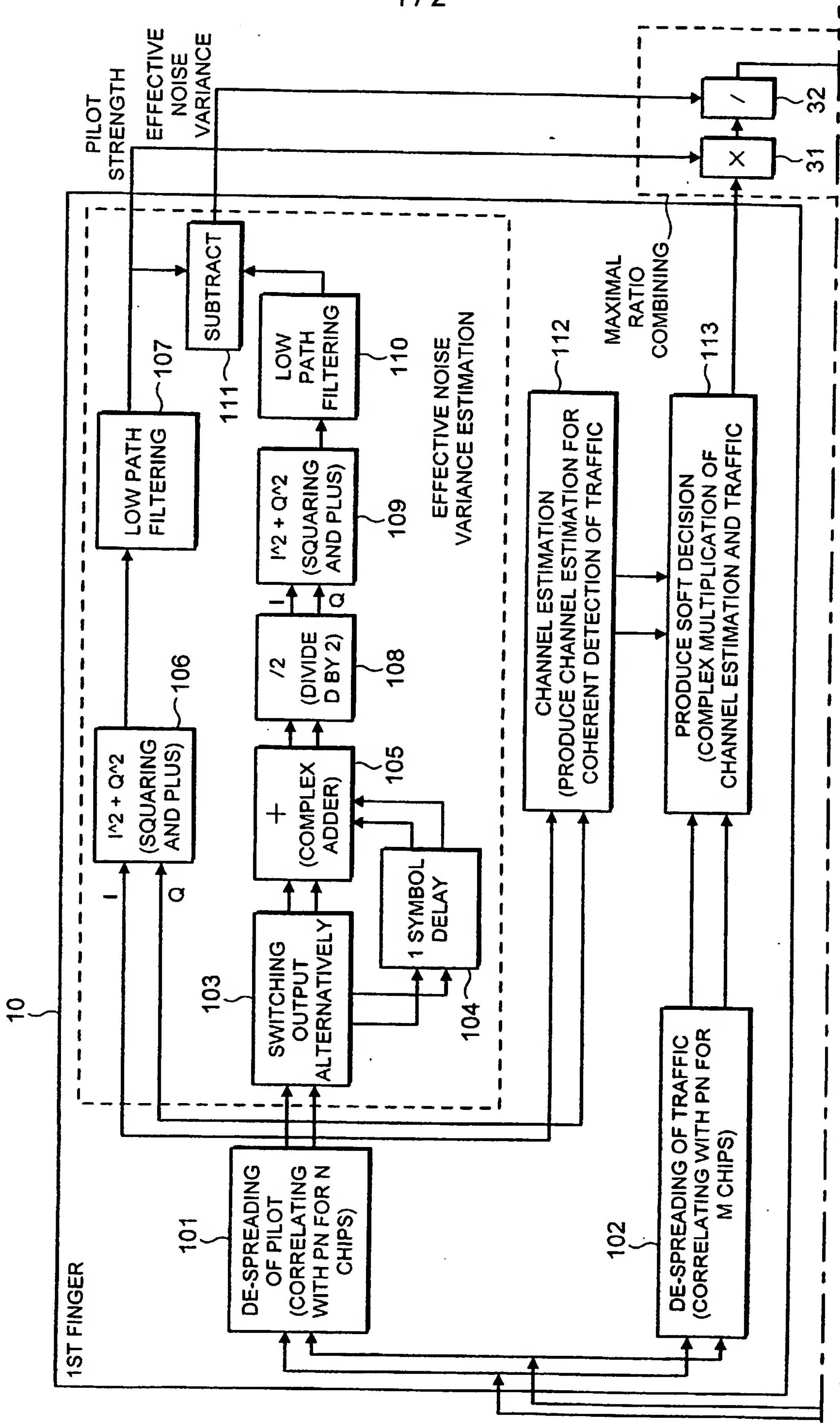
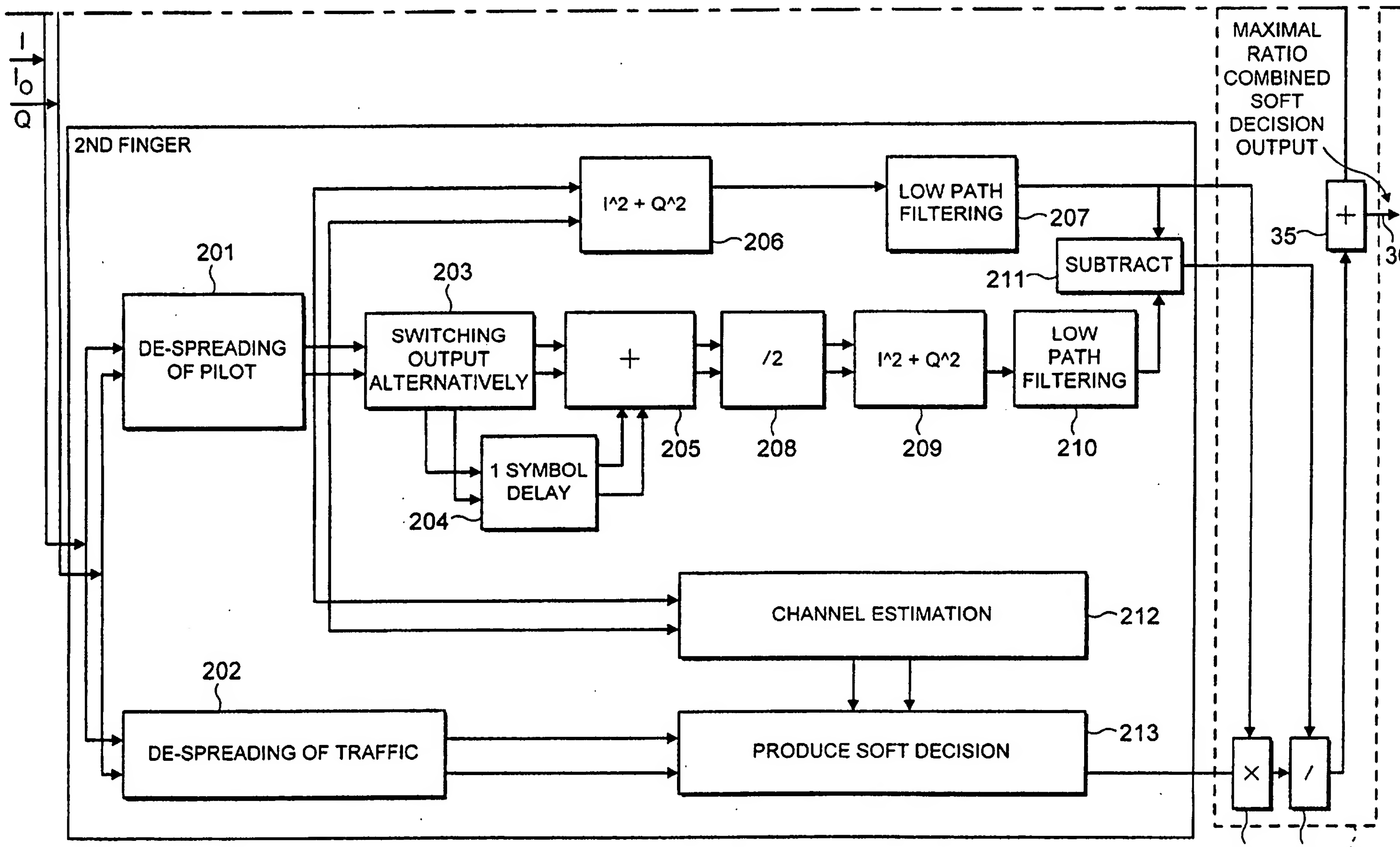

1ST FINGER
10
DE-SPREADING OF PILOT (CORRELATING WITH PN FOR N CHIPS)
101
DE-SPREADING OF TRAFFIC (CORRELATING WITH PN FOR M CHIPS)
102
SWITCHING OUTPUT ALTERNATIVELY
103
1 SYMBOL DELAY
104
+ (COMPLEX ADDER)
105
/2 (DIVIDED BY 2)
108
I^2 + Q^2 (SQUARING AND PLUS)
109
LOW PATH FILTERING
110
SUBTRACT
111
I
Q
I^2 + Q^2 (SQUARING AND PLUS)
106
LOW PATH FILTERING
107
EFFECTIVE NOISE VARIANCE ESTIMATION
CHANNEL ESTIMATION (PRODUCE CHANNEL ESTIMATION FOR COHERENT DETECTION OF TRAFFIC
112
PRODUCE SOFT DECISION (COMPLEX MULTIPLICATION OF CHANNEL ESTIMATION AND TRAFFIC
113
PILOT STRENGTH
EFFECTIVE NOISE VARIANCE
×
31
/
32
MAXIMAL RATIO COMBINING

FIG. 1



I
I0
Q
2ND FINGER
201
DE-SPREADING OF PILOT
202
DE-SPREADING OF TRAFFIC
203
SWITCHING OUTPUT ALTERNATIVELY
204
1 SYMBOL DELAY
205
+
/2
208
I^2 + Q^2
209
LOW PATH FILTERING
210
I^2 + Q^2
206
LOW PATH FILTERING
207
SUBTRACT
211
CHANNEL ESTIMATION
212
PRODUCE SOFT DECISION
213
MAXIMAL RATIO COMBINED SOFT DECISION OUTPUT
+
35
36
×
33
/
34
30

FIG. 1 cont'd

COMMUNICATIONS SYSTEMS

FIELD OF THE INVENTION

The present invention relates to communications systems, and in particular to methods of estimating of effective noise variance in receivers used in communications systems using pilot signals, for example in RAKE receivers used in CDMA systems.

BACKGROUND OF THE INVENTION

In CDMA (code division multiple access) communications systems each multipath signal can be separately tracked and de-spreaded by a receiver "finger", provided that the delay between paths is larger than the spreading chip rate. A combiner can then be used to combine the statistics from each path to produce a final statistic for demodulation. Even if each path endures severe fading independently, the combined signal remains stable, so that reliable communication is achieved. This is the well-known RAKE receiver. For example, see "Digital Communication" by Proakis, Third Edition (McGraw-Hill) pages 797 to 806.

The widely used optimum criterion for combining outputs from the receiver fingers is maximal ratio combining, i.e. to produce a combined output with a maximal signal-to-noise ratio (SNR). To achieve this aim, the relative value of each path's signal power and noise variance after de-spreading should be known. In the IS-95 and Globalstar (TM) CDMA system, for example, a pilot channel is always transmitted along with traffic channels to assist coherent demodulation. Also all channel signals from the same gateway are kept orthogonal using Walsh modulation as used in the IS-95 and Globalstar (TM) CDMA standards. The signal power of each path after de-spreading can be easily estimated

from the pilot channel, but the noise variance is not obvious. The noise here is a kind of effective noise since interference from the orthogonal channels will be removed through de-spreading and only signals from non-orthogonal channels are left.

At the receiver side, the received signal is the summation of signal from all paths plus other non-orthogonal interference. Obviously, all channel signals from the same path are mutually orthogonal due to orthogonal modulation but signal from different paths are generally non-orthogonal because of random path delay. If signal power from each path is different, which is the case in fading, then there will be differences in effective noise variances in the receiver fingers. Depending on channel conditions, this difference could be several dB. If no attempt is made to estimate the effective noise variance within each finger, then the whole noise variance is used instead of individual effective noise variance. This implicitly assumes that the effective noise variances for all fingers are the same. However, this is typically not true, and so such a technique will suffer loss of performance because it is not a true maximal ratio combining method. It is possible that with such a method, the combining could lead to worse SNR, compared with the finger having the best SNR among all individual fingers.

It is emphasised that the term "comprises" or "comprising" is used in this specification to specify the presence of stated features, integers, steps or components, but does not preclude the addition of one or more further features, integers, steps or components, or groups thereof.

SUMMARY OF THE PRESENT INVENTION

With techniques embodying the present invention, each finger's effective noise variance along with signal power (relative value) can be estimated, so that a true maximal ratio combining can be achieved. This should guarantee that a better performance (or equal when all finger's effective noise variances are the same) is always obtained, compared with the case without estimating effective noise variance, and also that combining always leads to improved SNR against an individual finger. In the following, the terms signal energy, power and strength are used. These terms mean the same thing in this particular case because for maximal ratio combining, only the relative values of signal powers between fingers are important.

Embodiments of the present invention can present simple but effective methods to estimate effective noise variance in each finger which is then used to realise real maximal ratio combining. Preferred embodiments make use of the pilot channel to realise effective noise variance estimation.

According to one aspect of the present invention, there is provided a method of determining the effective noise variance of an input signal to a communications receiver, the method comprising:

receiving an input signal of a first symbol set having a plurality of symbols which have respective signal power levels and associated noise components, the noise components having a first noise variance level;

calculating a second symbol set comprising a plurality of symbols, each of which has a signal power level corresponding to the average of the signal power levels of a respective pair of symbols from the first

symbol set and associated noise components, the noise components of the second symbol set having a second noise variance level; and

calculating the effective noise variance of the input signal using the average symbol power level of the first symbol set and the average symbol power of the second symbol set.

According to another aspect of the present invention, there is provided a method of determining the effective noise variance of an input signal to a RAKE receiver, the method comprising:

receiving an input signal having an input power and first and second symbol sets each of M symbols;

averaging the first and second symbol sets, to produce a third symbol set, the third symbol set having an average power volume; and

calculating the effective noise variance of the input signal using the input power value and the averaged power value of the third symbol set.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a RAKE receiver for use in accordance with one aspect of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

To aid explanation of the present invention, several symbols are used. Without loss of generality, a two path case is considered using the following notation:

I_{or1}: The total received power spectral density from path 1 (or satellite 1) in forward link.

I_{or2}: The total received power spectral density from path 2 (or satellite 2) in forward link.

I_{oc}: The power spectral density of a band-limited white noise source (simulating non-orthogonal interference) as measured at the user terminal (UT) antenna.

I_o: The total received power spectral, including signal from all paths (satellites) and interference, as measured at the UT antenna.

N_{t1}: The effective noise power spectral density of the non-orthogonal noise in finger 1 of the RAKE receiver.

N_{t2}: The effective noise power spectral density of the non-orthogonal noise in finger 2 of the RAKE receiver.

The following relation holds

$$I_0 = I_{or1} + I_{or2} + I_{oc} \qquad \text{i}$$

Assuming that the signal relating to I_{or1}, I_{or2} and I_{oc} are Gaussian with zero-mean value and are mutually independent, then the signal relating to I_o will also be Gaussian with zero-mean value.

Figure 1 illustrates a receiver having first and second fingers 10 and 20 respectively. The same total received signal I_o (made up of inphase (I) and quadrature (Q) components.) is received by the fingers 10 and 20, but each of them is tracking the signal from just a single path, I_{or1} or I_{or2}. In each finger, the de-spreading of the received pilot and traffic channels is carried out by separate despreading units 101, 102, 201, 202 which correlate respective signals with a PN code. Owing to the orthogonality of all channels from the same path (or satellite), a de-spreading operation using the correct timing and Walsh PN code (either for pilot or Traffic) in finger 1 will lead to a symbol E_{b1}

with all other I_{or1} channel signals having been removed. However, the interference from I_{or2} and I_{oc} will remain since they are non-orthogonal to I_{or1}, although the variances of the interfering signals will change due to correlation. This kind of noise without I_{or1} after de-spreading is the effective noise N_{t1}. Similarly in finger 2, a symbol E_{b2} will be obtained with non-orthogonal interference I_{or1} and I_{oc} remaining. This noise is the effective noise N_{t2}.

Within each finger, the de-spreading of pilot and traffic channels produce pilot and traffic symbols (101 and 102 in finger 1, and 201 and 202 in finger 2). Each symbol consists of a wanted signal part carrying information bit and an noise part. Of course for the pilot symbols, all signal parts in different symbols are the same since the information bits are the same (actually for pilot channel, all transmitted information can be assumed as 1). The waveform (if looking in time axis) of the two noises in pilot and traffic symbols are different. However, the power levels, i.e., noise variance, of the two noises are related to each other. In fact, if both the pilot and traffic channels are de-spreaded and accumulated for the same number of chips, the effective noise power levels are equal. Therefore, the noise power density of N_t in a de-spreaded traffic signal can be obtained by estimating that in the de-spreaded pilot signal.

In general, the de-spreading length for pilot and traffic channels are not necessarily the same. For example, if the de-spreading length for pilot is N, the traffic length may be N/2. In this case, the effective noise variance in de-spreaded traffic symbols is twice that in de-spreaded pilot symbols. Without loss of generality, the same de-spreading length for both pilot and traffic channels is assumed below.

Consider the pilot channel is de-spreaded and accumulated for N chips, which is the same number of chips for the Traffic channel symbol. The pilot symbol output (I and Q) contains useful signal energy plus effective noise. Let Si (i=1,2,..., 2M) be a set of pilot symbol outputs:

$$S_i = root(E) + n_i \qquad \text{ii}$$

Where E is the signal energy, which is the same in all S_i, and n_i is the effective noise term, which is independent Gaussian with zero-mean value and variance Nt. Each symbol Si consists of a constant signal part with energy E, plus a random noise term ni with variance Nt. To avoid confusion, the signal energy is used to indicate the signal part E, while symbol energy is used to indicate that of Si, which includes the effect of both E and ni.

Computing the averaged energy of the symbols in the set Si (summation for i=1 to 2M) leads to equation ii:

$$\left(\sum_{i=1}^{2M} S_i^2\right) \Big/ 2M = E + \left(\sum_{i=1}^{2M} n_i^2\right) \Big/ 2M + root(E) * \left(\sum_{i=1}^{2M} n_i\right) \Big/ M \qquad \text{iii}$$

The last term of expression can be ignored since it approaches zero when M is large. Also, a suitable approximation gives $(\Sigma n_i^2) = 2MNt$. Thus, the expression (iii) becomes:

$$\left(\sum_{i=1}^{2M} S_i^2\right) \Big/ 2M = E + Nt \qquad \text{iv}$$

Averaging every two consecutive symbols $S_{(2i-1)}$ and S_{2i} (i=1 to M) gives a new symbol set $\underline{S}i$:

$$\begin{aligned}\underline{S}_i &= \left(S_{2i-1} + S_{2i}\right)/2 \\ &= root(E) + \left(n_{2i-1} + n_{2i}\right)/2 \qquad \left(i = 1\ to\ M\right)\end{aligned} \qquad \text{v}$$

The term $(n_{(2i-1)} + n_{2i})/2$ in expression (v) is still Gaussian but now has a variance of Nt/2. The two consecutive symbol sets are averaged by averaging means, 103, 104, 105, 108. A complex addition is performed (105) to add a current symbol and a delayed symbol. A division (108) by two produces an average symbol value.

Computing the averaged energy of the symbols in the new symbol set $\underline{S}i$ (summing from i=1 to M) gives:

$$\left(\sum_{i-1}^{M} \underline{S}_i^2\right) \Big/ M = E + Nt/2 \qquad \text{vi}$$

Combining equation (vi) with equation (iv) gives:

$$Nt \Big/ 2 = \left(\sum_{i=1}^{2M} S_i^2\right) \Big/ 2M - \left(\sum_{i=1}^{M} \underline{S}_i^2\right) \Big/ M \qquad \text{vii}$$

It is then possible to estimate the effective noise variance Nt.

Equation (vii) gives the principle to estimate effective noise variance Nt. On the right side of equation (vii), the first term is the averaged symbol power of symbol set Si (i = 1, 2, …, 2M). The second

term is the averaged symbol power of the symbol set $\underline{S}i$ (I = 1, 2,..., M). Here $\underline{S}i$ = $(S_{(2i-1)} + S_{2i})/2$. In the above, the computation of symbol's averaged power is based on averaging 2M number of symbols for set Si (M number for set $\underline{S}i$). In practical implementations, this can be replaced by low pass filters, (107) and (110) as shown in figure 1. The two low pass filters' output are subtracted in (111), which implement the function of equation (vii). The output of (111) is the effective noise variance of finger 1. A factor of 2 of estimated variance (see equation (vii)) is not a problem, provided that both fingers have the same factor.

In fact, the estimation of effective noise variance Nt can be further used to obtain more accurate estimation of symbol signal energy E, or pilot strength. Referring to equation (iv), E is normally estimated using:

$$\left(\sum_{i=1}^{2M} S_i^2\right) \Big/ 2M \qquad \text{viii}$$

This estimate is acceptable if E >> Nt. However, if E is not significantly bigger than Nt, it will introduce bias. With the described embodiment of the present invention, an unbiased estimation of E can be obtained:

$$\begin{aligned} \textit{Unbiased estimate of } E &= \left(\sum S_i^2\right)\Big/2M - Nt \\ &= \left(\sum S_i^2\right)\Big/2M - 2*\left[\left(\sum S_i^2\right)\Big/2M - \left(\sum \underline{S}_i^2\right)\Big/M\right] \\ &= 2*\left(\sum \underline{S}_i^2\right)\Big/M - \left(\sum S_i^2\right)\Big/2M \end{aligned} \qquad \text{ix}$$

The second finger 20 operates in a similar manner for its channel.

In summary, if the pilot channel is coherently correlated for N and 2N chips, respectively, the mean value of the difference of the two squared correlation outputs equals to the effective noise variance of that finger. Thus, a RAKE receiver operated in accordance with the present invention can usefully determine the effective noise variance of each receiver finger.

With the effective noise variance obtained, maximal ratio combining of the two fingers will result in:

$$\textit{Combined soft decision} = \left(root\left(E_1\right) * S^1 / N_{t1}\right) + \left(root\left(E_2\right) * S^2 / N_{t2}\right)$$

x

Here S^1 and S^2 are soft decisions from fingers 1 and 2, E_1 and E_2 are corresponding signal energies and N_{t1} and N_{t2} are effective noise variances. The soft decision S1 and S2 are produced by 113 and 213 in figure 1. They are obtained by normal coherent demodulation method, i.e., a complex multiplication of the conjugate of channel estimation (I and Q) with the traffic symbol (I and Q) and then taking the real part. The estimates of E_1 and E_2 are obtained (106, 107) from de-spreaded pilot channel. As shown before, the estimates of E1 and E2 using this method are normally OK if E1 >> Nt1 and E2 >> Nt2, otherwise, the method shown in equation (ix) should be used to obtain a more accurate estimation. Note that E1 and E2 are the signal energies of the de-spreaded pilot symbols in fingers 1 and 2, respectively, but not that of the se-spreaded traffic symbols. However for maximal ratio combining, the pilot signal power instead of the traffic signal power can be used, provided that each finger's pilot signal power has the

same factor against the corresponding traffic signal power, i.e., the relative strength difference are kept.

From the outputs of the first finger 10, the soft decision and pilot signal strength are multiplied by a multiplier 31. The result of the multiplication is divided by the effective noise variance estimate by a divider 32. The outputs of the second finger are processed in a similar manner by multiplier 33 and divider 34. The results are added by adder 35 to produce output 36. This output is called combined soft decision, which can be fed to next stage channel decoder, for example Viterbi decoder in the case of convolutional coding, for channel decoding. After that, the information bits can be decided.

After maximal ratio combining has occurred, the SNR of the combined signal will be:

$$E_1/N_{t1} + E_2/N_{t2} \qquad \text{xi}$$

which is a simple addition of two SNRs from two paths. This indicates that the maximal ratio combining always leads to the improvement of SNR whatever the value of the original SNR within each path. For the two path case, the maximum improvement of SNR over each path is 3dB, which happens when the two paths have equal SNR.

Thus, embodiments of the present invention present simple but efficient methods to estimate effective noise variance in each finger of a RAKE receiver, which can be used to realize real maximal ratio combining results. Depending on channel conditions, for two path combining, the signal-to-noise ratio gain could be 1-2 dB, compared with the result without estimating of effective noise variance.

CLAIMS:

1. A method of determining the effective noise variance of an input signal to a communications receiver, the method comprising:

receiving an input signal of a first symbol set having a plurality of symbols which have respective signal power levels and associated noise components, the noise components having a first noise variance level;

calculating a second symbol set comprising a plurality of symbols, each of which has a signal power level corresponding to the average of the signal power levels of a respective pair of symbols from the first symbol set and associated noise components, the noise components of the second symbol set having a second noise variance level; and

calculating the effective noise variance of the input signal using the average symbol power level of the first symbol set and the average symbol power of the second symbol set.

2. A method as claimed in claim 1, wherein the second symbol set is calculated according to the equation:

$$\underline{S}_i = \left(S_{2i-1} + S_{2i}\right)/2 \qquad \left(i = 1 \text{ to } M\right)$$

in which $\underline{S}i$ represents the second symbol set, Si represents the first symbol set and 2M represent the number of symbols in the first symbol set.

3. A method as claimed in claim 1 or 2, wherein the noise variance level of the input signal is calculated according to the equation:

$$Nt/2=\left(\sum_{i=1}^{2M} S_i^2\right)\Big/2M-\left(\sum_{i=1}^{M} \underline{S}_i^2\right)\Big/M$$

In which Nt represents the input signal noise variance level, Si represents the first symbol set, 2M represents the number of symbols in the first symbol set and $\underline{S}$i represents the second symbol set.

4. A method of demodulating a input CDMA signal, comprising calculating the effective noise variance value of the input signal as claimed in claim 3, and combining outputs from a plurality of fingers of a RAKE receiver on the basis of the calculated effective noise variance for each finger of the receiver.

5. A method as claimed in claim 4, wherein the outputs of the fingers are combined according to the expression:

$$\sum_{j=1}^{N}\left(root\left(E_j\right)*S^j/N_{tj}\right)$$

in which N represents the total number of fingers in the RAKE receiver, E_j represents pilot channel energy for finger j, S^j represents a soft decision for finger j and N_{tj} represents the effective noise variance for finger j.

Application No:	GB 0017759.2	**Examiner:**	Gareth Griffiths
Claims searched:	All	**Date of search:**	13 February 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H4P (PAL, PAN, PEF, PEM, PRE, PRV)

Int Cl (Ed.7): H04B 1/10, 1/707, H04L 1/20, 25/03, 27/06, 27/14, 27/22, 27/38

Other: Online Databases: WPI, EPODOC, JAPIO, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB2263048 A (MOTOROLA)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		